Science of the Total Environment 665 (2019) 52–60

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

BRIC and MINT countries' environmental impacts rising despite alleviative consumption patterns

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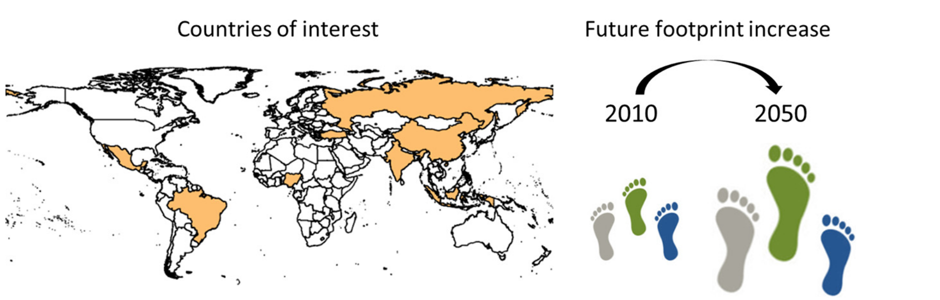
HIGHLIGHTS

- Footprints from household consumption increase up to sevenfold from 2010 to 2050.
- Increases in environmental impacts are mainly driven by economic growth.
- Changes in household consumption patterns attenuate impact increases up to >50%.
- Most emerging economies show a weak decoupling between expenditure and impacts.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 23 November 2018
Received in revised form 21 January 2019
Accepted 7 February 2019
Available online 8 February 2019

Editor: Deyi Hou

Keywords:
Climate change
Demand-side projections
Household consumption
Land degradation
Multi-regional input-output analysis
Water scarcity

ABSTRACT

The BRIC (Brazil, Russia, India, China) and MINT countries (Mexico, Indonesia, Nigeria, Turkey) shifted the economic weight from developed to emerging countries. They will continue to grow rapidly by population and gross domestic product (GDP), which could also imply environmental changes. We use the environmentally extended multi-regional input-output database EXIOBASE in a consumption-based approach to assess carbon, land, and water footprints of four income groups within each of these emerging economies in 2050 compared to our base year 2010. We estimate that consumption changes make environmental impacts increase by a factor of 1.6 (for Russia's water footprint) to a factor of 7.0 (for Nigeria's carbon footprint). This rise is mostly driven by GDP growth, but often also by population growth. Changes in consumption patterns due to income growth, however, attenuate the effect. The attenuation appeared to be much stronger for water (for India and Indonesia over 50%) than for land or carbon footprints. It is hence important that forward-looking modelling exercises account for different income categories and related expenditure patterns. The results further indicate how much our technologies must improve to compensate for impact increases induced by rising consumption. To cope with that, not only established economies, but also some BRIC and MINT countries, especially Russia and China, must increase their efforts towards environmental sustainability.

1. Introduction

The economic weight is shifting from developed to emerging economies. Already in the year 2001, O'Neill (2001) recognised the growing economic weight of Brazil, Russia, India, and China, which he coined the BRIC countries. In 2013, he further recognised the importance of emerging markets in Mexico, Indonesia, Nigeria, and Turkey, for

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https://doi.org/10.1016/j.scitotenv.2019.02.103
0048-9697/

which he popularised the term MINT countries (O'Neill, 2013). China displaced the United States in 2014 as the world leader in terms of the gross domestic product (GDP) in purchasing power parity (IMF, 2017). In 2018, China still ranked first, India ranked third, Russia sixth, Indonesia seventh, Brazil eighth, Mexico eleventh, Turkey thirteenth, and Nigeria twenty-fourth (IMF, 2017).

The BRIC and MINT countries will continue to grow both by population and GDP. With a population that is getting larger and richer, the environmental pressure exerted on the environment increases (Bradshaw et al., 2010; Scherer et al., 2018; Ward et al., 2016). There is a hypothesis that environmental impacts follow the environmental Kuznet curve, an inverted U-shape, where impacts first rise with income and later decline. However, an analysis of energy requirements in five countries, including Brazil and India (Lenzen et al., 2006), and of various environmental impacts in over 170 countries (Bradshaw et al., 2010) have both not found evidence supporting the environmental Kuznet curve hypothesis, although impacts slightly reduced at very high incomes (Bradshaw et al., 2010). Thus, we can expect increased environmental pressures in the future.

Several studies have analysed environmental impacts of households in different income groups for single countries, such as India (Ekholm et al., 2010) and China (Fan et al., 2012; Feng et al., 2011; Wiedenhofer et al., 2017), up to 166 countries (Scherer et al., 2018). Most studies focus on energy use or carbon footprints (Ekholm et al., 2010; Fan et al., 2012; Feng et al., 2011; Wiedenhofer et al., 2017), while only few studies investigate multiple impact categories (Scherer et al., 2018). All of these studies highlight the increased environmental impacts of individuals in higher income groups, which supports the suggestion that economic growth leads to more severe environmental degradation.

Since emerging economies like the BRIC and MINT countries are still expected to undergo major demographic and economic changes (OECD, 2014; UN, 2014), a look into the future of household footprints is highly relevant for sustainable development planning. Economy-environment models, such as computational general equilibrium (CGE) models, provide a limited sector detail (Tukker et al., 2018). For example, the Global Trade Analysis Project (GTAP) only distinguishes 57 sectors as opposed to 200 products represented in the environmentally extended multi-regional input-output database EXIOBASE (Tukker et al., 2018). In addition, CGE models usually represent all households by a single type. Long-term environmental analyses, however, require the distinction of households by income and consumption patterns (van Ruijven et al., 2015). Few studies have projected the consumption of different household types and their associated environmental impacts. Ekholm et al. (2010) projected energy use for cooking in India from 2000 to 2020, and Dai et al. (2012) projected energy use and carbon emissions in China from 2005 to 2050. The latter study estimates that carbon emissions of Chinese households will more than double from 2010 (our base year) to 2050. Here, we assess future carbon, land, and water footprints of households at high product detail in eight emerging economies, the BRIC and MINT countries (covering 50% of the global population in 2017 (World Bank, 2018b)), taking into account population growth, income rise, and changing expenditure patterns from 2010 to 2050.

Reducing the environmental impacts related to the production and consumption of products in an economy with a stagnating population and low economic growth can be difficult. For countries with high population and economic growth the challenges are even bigger. With increasing population, income levels, and associated expenditures, the environmental impacts can only be reduced by reducing the environmental impacts of production, unless there is a shift to low-impact final demand categories. This paper is one of the first to analyse the impact of all these factors for a broad set of environmental indicators. By keeping the structure of the economy unchanged, this study shows how much production must improve to counteract population growth and increased income levels.

2. Methods

2.1. Household expenditures

The Global Consumption Database of the World Bank contains expenditure patterns of 106 products and services for 91 developing and emerging countries in 2010 (World Bank, 2017). All the eight countries under investigation in this study are available in there. The database distinguishes four income groups, split by absolute monetary boundaries in international dollars: lowest ≤ \$2.97, low = \$2.97–8.44, middle = \$8.44–23.03, and higher ≥ \$23.03 per capita per day. Multiplying the per-capita expenditures with the population of each income group results in total expenditures per income group. These expenditure patterns are used in input-output analyses with EXIOBASE (see next section). To link both databases, the expenditures of the World Bank are translated with a bridge matrix to the EXIOBASE classification, which consists of 200 products and services (Scherer et al., 2018).

2.2. Environmentally extended multi-regional input-output analyses

We perform environmentally extended multi-regional input-output analyses (EE-MRIO), using the product-by-product version 3.4 of EXIOBASE (Stadler et al., 2018) based on the industry technology assumption. It links economic flows between 200 product groups for 49 countries or regions. Of the eight countries under investigation, seven are included as a separate unit, while Nigeria is part of the rest-of-the-world region for Africa. This implies that, although the expenditure patterns are specific to Nigeria, the economic structure of Nigeria is the same as the average structure of Africa (without South Africa).

The impacts of a country's consumption are assessed with the Leontief model:

$$\mathbf{I} = \mathbf{Q}\cdot\left(\mathbf{B}\cdot(\mathbf{1}-\mathbf{A})^{-1}\cdot\mathbf{F} + \mathbf{D}\right)$$

where **I** is the impact matrix with income groups represented in the columns. **Q** is the characterization matrix that translates emissions or resources into impacts. **B** is the matrix that provides the emissions and resources per product unit. $(\mathbf{1}-\mathbf{A})^{-1}$ is the Leontief inverse that expresses the total product output required to produce one unit of a product, **1** is the identity matrix, and **A** is the structural matrix of the economy, also called technology matrix (Miller and Blair, 2009). **F** is the final demand or the expenditure pattern as derived in the previous section. Lastly, **D** describes the direct household emissions and resources, also disaggregated into income groups. Direct emissions and resources are allocated to the four income groups based on the expenditure of associated products: fuels for impacts related to greenhouse gas emissions, real estate services for those related to land use, and water services for those related to water consumption (Scherer et al., 2018).

We characterize the environmental impacts through matrix **Q** for three impact categories – climate change, land use, and water consumption. Climate change impacts are assessed by the carbon footprint expressed in kg CO_2-equivalents. It considers greenhouse gas emissions and their 100-year global warming potentials (IPCC; Myhre et al., 2013). Land use is converted to a land footprint in km^2-equivalents using land stress indices (LSI; Pfister et al., 2011). These stress indices are the ratio of the site-specific net primary productivity of the natural reference vegetation (NPP_0; Haberl et al., 2007) to the global maximum ($NPP_{0,max}$). The consumption of surface and groundwater is translated to water scarcity footprints (in the following shortened to water footprints) in million m^3-equivalents using the average of two water scarcity index (WSI) estimates (Pfister and Bayer, 2014; Scherer and Pfister, 2016). Such water scarcity indices are derived from the water consumption-to-availability ratio.

2.3. Decoupling

The elasticity (e), or decoupling degree, between two variables describes the ratio of their relative changes, often of an environmental impact to the gross domestic product (GDP). Absolute (strong) decoupling implies that the environmental impact reduces while GDP grows ($e < 0$), relative (weak) decoupling implies that both increase but the environmental impact to a lesser extent ($0 < e < 0.8$), and expansive coupling implies that both increase but the environmental impact to a greater extent ($0.8 < e < 1.2$) (Tapio, 2005; Ward et al., 2016). Here, we use the same concept to compare the relative changes in expenditure or final demand (f) and impact (i). Formally, we define the elasticity as

$$e = \frac{\frac{\Delta i}{i_{lowest}}}{\frac{\Delta f}{f_{lowest}}} = \frac{f_{lowest} \cdot \Delta i}{i_{lowest} \cdot \Delta f}$$

2.4. Demand-side projections

The expenditures and associated impacts were projected to the year 2050. The scenario considered population change based on the United Nations' prospects (UN, 2014) and an increase in wealth based on OECD's forecast of the gross domestic product (GDP; OECD, 2014). Only for Nigeria, the GDP forecast was obtained from an alternative source. The IMF provides GDP estimates including for the year 2010 and a forecast until the year 2022 (IMF, 2017), while PricewaterhouseCoopers provide a forecast until 2050 compared to the year 2016 (Hawksworth et al., 2017). Consumer price indices from the World Bank (2018a) allowed to convert all GDP estimates to constant 2010 US dollars as a common unit. A conversion to EUR, the monetary unit in EXIOBASE, was not required, as only the relative changes in GDP are needed for the projections.

We assumed a uniform distribution of incomes within the boundaries of an income group. The missing upper boundary of the highest income group was estimated by comparing the total expenditure with that of the preceding middle income group. The resulting hypothetical individual incomes were then multiplied with the factor increase in GDP between 2010 and 2050. The new individual incomes were reassigned to the corresponding income classes. This yields a new income distribution with generally a higher share of people in higher income classes, and new average incomes within an income group. Finally, the income and population changes were used to rescale the final impacts resulting from the EE-MRIO for 2010 (Section 2.2).

The structure of the economy and associated environmental intensities remained unchanged. These might actually change over time. de Koning et al. (2015) considered such changes in their scenarios. However, it entails many uncertainties, and was beyond the scope of this study. Instead, our study indicates how much our technologies must improve to compensate for impact increases induced by consumption changes.

2.5. Decomposition

The impacts (i) can be decomposed into population (p), affluence (a), and the impact intensity of the consumption or expenditure pattern (c):

$$i = p \cdot a \cdot c = p \cdot \frac{gdp}{p} \cdot \frac{i}{gdp}$$

The individual contributions of changes in those drivers (because of a new income distribution) to the increases in impacts were evaluated with an index decomposition analysis (IDA). We use the logarithmic mean Divisia index (LMDI), as recommended by Su and Ang (2012) and developed by Ang et al. (1998):

$$\Delta h = h_{2050} - h_{2010} = \Delta h_p + \Delta h_a + \Delta h_c$$

$$\Delta h_p = \frac{h_{2050} - h_{2010}}{\ln(h_{2050}) - \ln(h_{2010})} \cdot \ln\left(\frac{p_{2050}}{p_{2010}}\right)$$

$$\Delta h_a = \frac{h_{2050} - h_{2010}}{\ln(h_{2050}) - \ln(h_{2010})} \cdot \ln\left(\frac{a_{2050}}{a_{2010}}\right)$$

$$\Delta h_c = \frac{h_{2050} - h_{2010}}{\ln(h_{2050}) - \ln(h_{2010})} \cdot \ln\left(\frac{c_{2050}}{c_{2010}}\right)$$

where Δh_p, Δh_a, and Δh_c are the changes in impacts due to changes in population, affluence, consumption pattern.

3. Results

3.1. Decoupling

With higher incomes, the environmental impacts per capita increase, while they mostly decrease per monetary unit (Fig. 1, Figs. A1–7 in the Appendix). The higher impacts per capita reflect the higher spending of individuals with higher incomes. However, the consumption shifts from high-impact necessities like food (in China in 2010: 47% of total expenditure for the lowest and 24% for the higher income group) to low-impact luxuries like services (in China in 2010: 17% of total expenditure for the lowest and 28% for the higher income group). Therefore, environmental impacts increase slower than a country's GDP.

Most countries experience a relative (weak) decoupling between expenditure and any environmental impact (Fig. 2, Figs. A8–14 in the Appendix). Exceptions are the land and carbon footprints of Russia and especially the land footprint of India ($e = 1.14$), which show expansive coupling with the respective country's expenditure. Especially, India's land stress from vegetable, fruit, and nut consumption increases a lot with income, and dominates the land footprint of the low, middle, and higher income groups. The strongest relative decoupling occurs between the water footprint and expenditure in India ($e = 0.13$). Averaged across all three environmental footprints, Indonesia experiences the strongest relative decoupling ($e = 0.31$, Fig. 2), followed by Nigeria ($e = 0.44$) and Mexico ($e = 0.46$).

3.2. Demand-side projections

Without technical or structural economic change, the combined effect of expected population growth, GDP growth, and change in consumption patterns will lead to an increase in environmental impacts until 2050 for all BRIC (Fig. 3, Fig. A15 in the Appendix) and MINT countries (Fig. 4, Fig. A16 in the Appendix). The environmental change of countries increases in the following order: Russia, Brazil, Mexico, Turkey, Indonesia, China, India, and Nigeria. The increases range from a factor of 1.6 for Russia's water footprint to a factor of 7.0 for Nigeria's carbon footprint. In Russia, the environmental change is least severe. Its GDP increases less and it is the only country whose population shrinks. Still, as mentioned, the water footprint increases by a factor of 1.6, and the land and carbon footprints double. On the other extreme, Nigeria's environmental change is enormous. Its population almost triples and its GDP increases almost ninefold. This leads to increases in water, land, and carbon footprints by a factor of 5.9, 6.9, and 7.0. Except for Brazil where the land footprint increases slightly less than the water footprint, water footprints increase the least. Notable is also that India's land footprint increases much more (by a factor of 6.9) than its carbon and water footprints (by factors of 4.1 and 2.3). This can be explained by the expansive coupling of the land footprint as opposed to the weak decoupling of carbon and water footprints, as pointed out above.

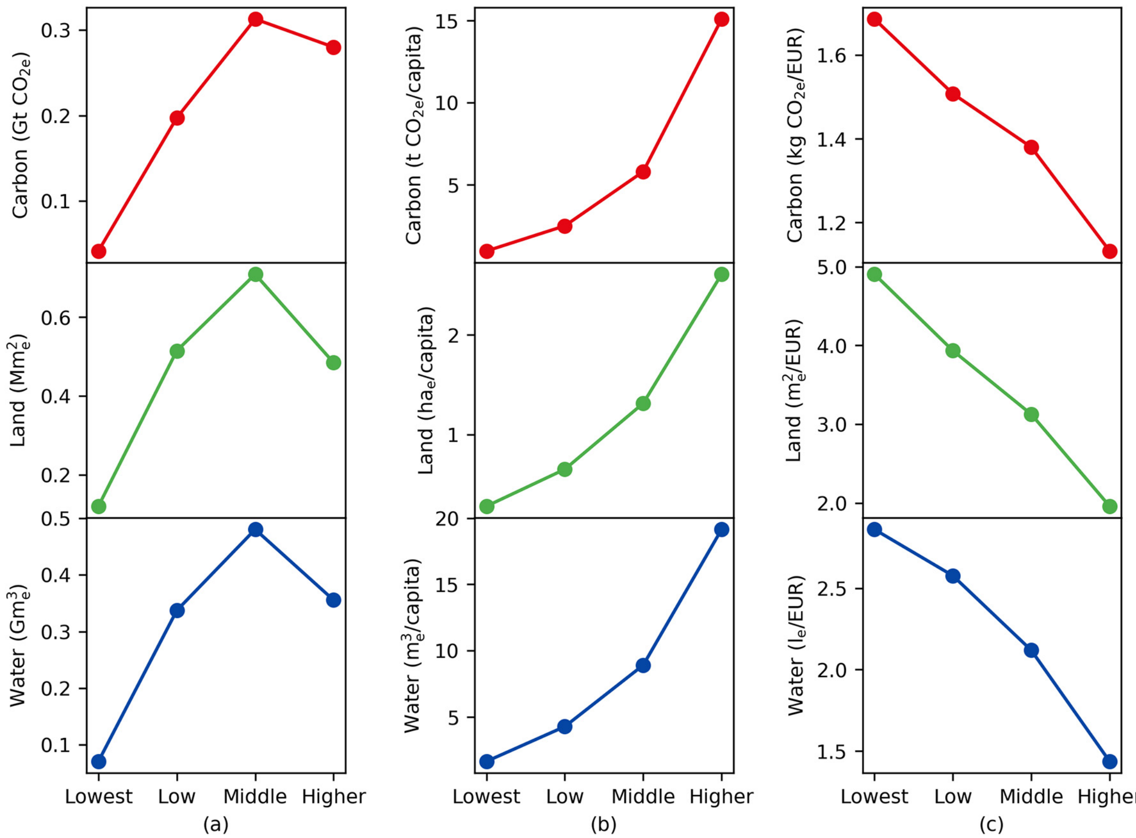

Fig. 1. Environmental impacts of Brazil. Columns represent (a) total environmental impacts, (b) environmental impacts per capita, and (c) environmental impacts per EUR. Red indicates carbon footprints, green indicates land footprints, and blue indicates water footprints.

3.3. Decomposition

The increases in impacts are mostly driven by increases in GDP per capita (Table 1), leading to higher expenditures. Except for Russia with a shrinking population, population growth also drives impact increases. In Nigeria, the influence of population growth is almost as strong as the growth in GDP per capita. The changes in consumption patterns from low to high income groups attenuate the increase in impacts, in line with the decreasing environmental intensity per monetary unit mentioned above (Fig. 1, Figs. A1–7 in the Appendix). For example, the higher expenditures for services observed in higher income groups have a limited contribution to the carbon footprint, and hardly affect the land and water footprints. The attenuation effect is most significant for the water footprint in India and Indonesia. Without the attenuation effect, the water footprint would rise 240 or 220%, respectively, but by including the attenuation effect this rise is roughly halved. Food clearly dominates the water footprint. While the mid-range value of the middle income group (dominating in India in 2050) is 10 times higher than of the lowest income group (dominating in India in 2010), only 3 times more is spent on food.

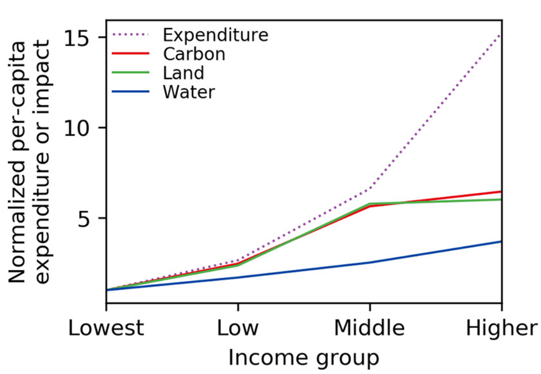

Fig. 2. Decoupling between household expenditure and environmental footprints in Indonesia.

3.4. The challenges ahead

We can express the increasing carbon, land, and water footprints in terms of percentage growth per year (Table 2) so that they can be compared with annual observed rates in technological improvements.

The calculated growth rates for the carbon, land, and water footprints range from 1.2% to 5.0% per year with 19 out of the 24 rates (far) above 2% per year. If the BRIC and MINT countries' water, land, and carbon footprints are to be kept stable at the 2010 level, these growth rates must be counteracted (see Section 4.3).

4. Discussion

4.1. Comparison with other studies

Several studies support the finding that environmental impacts per monetary unit mostly decrease with higher incomes (Lenzen et al., 2006; Sommer and Kratena, 2017; Wier et al., 2003; Wier et al., 2005), as changes in consumption patterns partly compensate for the increases in the level of consumption (Munksgaard et al., 2000; Munksgaard et al., 2001). Others also observed the shift from necessities to less environmentally intensive luxuries (Lenzen et al., 2006; Wier et al., 2001). As mentioned above, this explains why wealth increases faster than

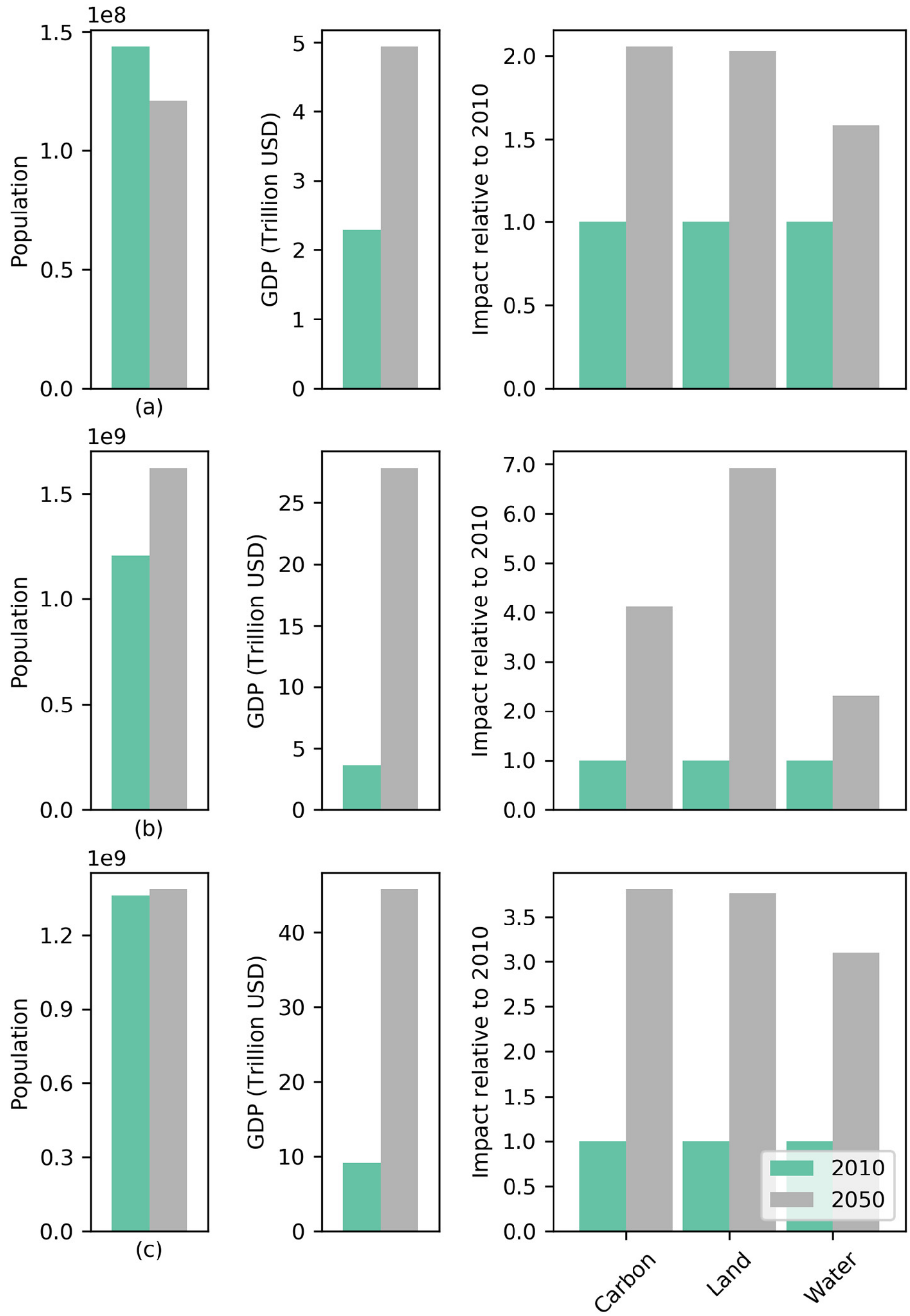

Fig. 3. Projection of environmental impacts by (a) Russia, (b) India, and (c) China.

environmental pressures (Munksgaard et al., 2005). Income or expenditure elasticities related to environmental pressures, mostly being <1 (Lenzen et al., 2006; Wier et al., 2001), point into the same direction. A notable exception is the expenditure elasticity above 1 for direct household energy requirements in Brazil (Cohen et al., 2005), which complicates sustainable development.

As presented in the results, water footprints increase less than land or carbon footprints. This is consistent with the observation that environmental inequalities are lower for water than for the other environmental footprints (Scherer et al., 2018).

Affluence was also identified in previous studies as a more important driver of environmental change than population. For example, affluence was the main driver of greenhouse gas emission changes in Australia (Wood, 2009) and Norway (Yamakawa and Peters, 2011), and of CO_2 emission changes during economic growth and economic recession in the United States (Feng et al., 2015). The same applies to CO_2 emission changes during economic growth and economic recession in countries of the former Soviet Union, including Russia as a BRIC country (Brizga et al., 2013). Likewise, Guan et al. (2008) point to affluence as the main driver of CO_2 emissions in China, and to the challenge to stabilize its future emissions, as efficiency improvements are expected to be insufficient. Although population growth has been the largest driver of energy use and CO_2 emission increases in Brazil between 1970 and 1996/2008, affluence was the larger driver during periods of economic growth (Lenzen et al., 2013b; Wachsmann et al., 2009). The authors of the Brazilian study also doubt that improvements at the production side will be effective enough to limit the emissions.

Most of the studies mentioned in the previous paragraph have applied structural decomposition analyses (SDA), with the exception of Brizga et al. (2013) who have applied an index decomposition analysis

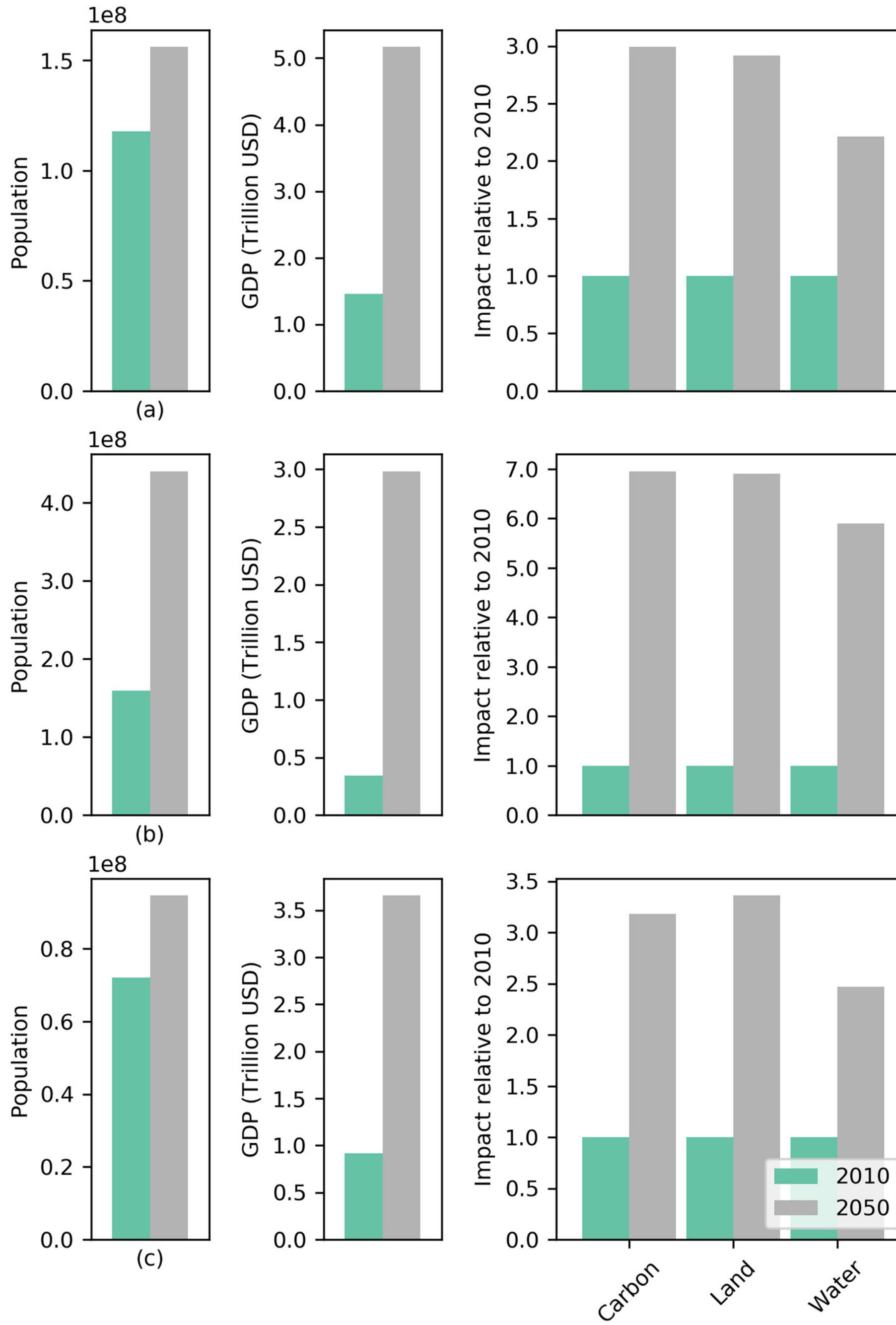

Fig. 4. Projection of environmental impacts by (a) Mexico, (b) Nigeria, and (c) Turkey.

(IDA), as done here as well. Both are valid approaches. While SDA uses the input-output tables and allows for more detailed decompositions, IDA is easier to use, sufficient for the three demand-side factors of interest in this study, and more widely used especially outside of the specialized field of industrial ecology (Hoekstra and van den Bergh, 2003). Both approaches yield different results from different perspectives (Hoekstra and van den Bergh, 2003). Therefore, it is valuable to see that, despite different methodological choices compared to most above mentioned decomposition studies, our study leads to similar conclusions.

For the demand-side projections, an alternative approach could have been used. Future environmental impacts could also have been derived from the elasticities calculated in Section 2.3, following Lenzen et al. (equ. 5 in Lenzen et al., 2013a).

4.2. Limitations of the study

The results point to enormous increases in environmental impacts of emerging economies from 2010 to 2050 if our production system remains the same. They range up to a factor of 7.0 for Nigeria's carbon footprint. This happens despite the fact that the higher income groups, that become larger at a higher GDP, have a lower than average impact per monetary unit spent. Urbanisation was disregarded in the projection. Besides migration from rural areas into cities, it is also caused by natural population growth in cities. The latter is often overlooked, but was found to be the dominant driver of urbanisation in sub-Saharan Africa (Parnell and Walawege, 2011). Several studies have shown differences in consumption patterns and associated energy use or carbon footprints between rural and urban households (Ekholm et al., 2010;

Table 1
Decomposition of environmental change drivers (population *p*, affluence *a*, and intensity *c*).

Country	Driver	Carbon	Land	Water
Brazil	Population	19.8	23.6	22.2
	Affluence	93.6	111.4	105.2
	Intensity	−13.4	−35.0	−27.4
Russia	Population	−23.9	−24.3	−37.6
	Affluence	130.7	133.1	205.3
	Intensity	−6.8	−8.7	−67.7
India	Population	20.9	15.3	35.2
	Affluence	123.1	90.1	207.6
	Intensity	−44.0	−5.4	−142.8
China	Population	1.4	1.4	1.6
	Affluence	119.2	120.2	140.7
	Intensity	−20.6	−21.6	−42.3
Mexico	Population	25.6	26.2	35.4
	Affluence	89.9	92.0	124.1
	Intensity	−15.6	−18.2	−59.5
Indonesia	Population	22.8	22.8	33.7
	Affluence	124.9	125.0	185.0
	Intensity	−47.7	−47.8	−118.7
Nigeria	Population	52.3	52.5	57.1
	Affluence	59.3	59.5	64.7
	Intensity	−11.6	−11.9	−21.9
Turkey	Population	23.4	22.4	30.0
	Affluence	96.4	92.0	123.5
	Intensity	−19.8	−14.4	−53.5

Feng et al., 2011; Wiedenhofer et al., 2017). According to the urban compaction theory, increased urban density might benefit the environment. However, a study on how urbanisation affects energy use and carbon emissions in 99 countries did not provide evidence for this theory (Poumanyvong and Kaneko, 2010). The researchers divided the countries into three income groups, and found varying effects among these groups. Only in low-income countries, energy use decreases with urbanisation. Still, carbon emissions increase with urbanisation in all three types of countries. The emission increase is most pronounced in middle-income countries, to which four of the six included BRIC and MINT countries belong (Poumanyvong and Kaneko, 2010).

4.3. Counteracting demand-driven impact increases

The estimated growth in environmental footprints due to changes at the demand side could be counteracted by two approaches. Production must become much less emission- and resource-intensive, and/or consumption must shift more radically to low-impact expenditure categories as assumed in our analysis (Grubler et al., 2018). The alternative would be to not pursue the levels of economic growth we used in our assessment. Particularly for carbon (even neglecting the significant absolute reductions usually deemed necessary (IPCC, 2018)), it requires emission intensity improvements well beyond historical levels. Historical rates of energy efficiency improvement range from 0.6% to 2.3% (Mahony, 2013; Raupach et al., 2007; Steckel et al., 2011), which is much lower than the growth rates in Table 2. This implies that a decarbonisation rate of 2–3% per year of the energy supply chain is necessary for 40 years in a row just to keep the carbon footprint stable in the BRIC and MINT countries.

Table 2
Annual growth rates per year of the carbon, land, and water footprints assuming a compound growth rate as a result of changing demand.

Country	Carbon (%)	Land (%)	Water (%)
Brazil	2.2	1.8	1.9
Russia	1.8	1.8	1.2
India	3.6	5.0	2.1
China	3.4	3.4	2.9
Mexico	2.8	2.7	2.0
Indonesia	3.2	3.2	2.2
Nigeria	5.0	5.0	4.5
Turkey	2.9	3.1	2.3

4.4. Trade-offs and responsibilities

The socio-economic development of the BRIC and MINT countries, as modelled here, conflicts with the environment. Similar trade-offs were also identified among social and environmental Sustainable Development Goals (Scherer et al., 2018). If we aim at a socially just and environmentally safe operating space for humanity (O'Neill et al., 2018), developing and emerging countries must be given the opportunity to further develop, which makes it difficult to avoid increased environmental degradation. Ward et al. (2016) demonstrated that energy and material use cannot fully be decoupled from GDP growth. However, they also point out that GDP is a poor proxy for societal wellbeing, and that countries can sustainably improve their wellbeing if they abandon their focus on GDP growth and instead aim at more comprehensive measures of wellbeing.

Emerging economies embrace “common but differentiated responsibilities” in the management of global environmental challenges (Destradi and Jakobeit, 2015). This principle is also endorsed by the scientific community, and relates to the concept of ecological debt (Warlenius et al., 2015). According to this concept, countries are accountable for historical ecological damage and use of ecosystem services, and where this is disproportionate, they accrue an ecological debt. In contrast, countries who have previously been put at a disadvantage are now entitled to disproportionately benefit at the expense of debtor countries (Warlenius et al., 2015). Srinivasan et al. (2008) found that the ecological debt of rich countries is higher than the monetary foreign debt of poor countries, and that this is especially due to their cumulative greenhouse gas emissions. Several other studies have applied the concept specifically to the carbon debt. To meet the climate target of 2 °C, developed countries face reduced carbon budgets and must reduce their emissions immediately, while developing countries might use a carbon budget larger than their historically accumulated emissions and delay their emission peak (Alcaraz et al., 2018). India especially benefits from this concept, while Russia has already accrued a carbon debt, and China is estimated to accrue a carbon debt until 2050 (Alcaraz et al., 2018; Gignac and Matthews, 2015). Therefore, Peters et al. (2015) suggest that not only the emission pledges of developed regions like the EU and the US are too low to be considered fair, but also the pledge of China. Mayer and Haas (2016) analyse cumulative resource use, and approximate the ecological debt of a country with its degree of net-import dependency. Based on that definition, they found that Turkey, China, and India have accrued small ecological debts, while Russia, Brazil, Mexico, Indonesia, and especially Nigeria are ecological creditors.

5. Conclusions

Environmental impacts in BRIC and MINT countries will grow due to expected rise in GDP per capita and population growth. At the same time, our analysis found that the carbon, water, and land footprints per monetary unit of consumption are generally lower in the higher income groups. Since higher income groups will spent a larger part of the GDP in the future, we found that for most BRIC and MINT countries a relative decoupling between growth in household expenditure and any associated environmental impacts will occur. Assuming an unchanged economic production structure, population growth, GDP growth, and attenuation by changes in household expenditure will lead to impacts increased by a factor of 1.6 (for Russia's water footprint) to a factor of 7.0 (for Nigeria's carbon footprint) between 2010 and 2050. This illustrates how much production must improve to counteract population growth and increased income levels.

The attenuation of the growth in impacts due to changes in household expenditure patterns at higher incomes can be significant. Our

decomposition analysis shows that the growth of the water footprints of India and Indonesia are around 50% lower than one would estimate using a simple extrapolation based on GDP growth. It is hence highly relevant that in forward-looking modelling exercises expenditure patterns are distinguished that are specific to each income group. This is often not yet the case, since most models distinguish just one final demand vector for households in general. We also found that the attenuation differs across the types of impacts. For the carbon footprint, for instance, the attenuation is much less pronounced than for water. A reason for this is that the water footprint is largely related to food consumption, and that expenditure on food tends to become a smaller fraction of total expenditure for higher-income groups.

Altogether, only high emission reductions and efficiency gains in our production system can mitigate the significant calculated rise in impacts. The alternative is to pursue less economic growth as assumed here, or to embark on radical shifts to low-impact consumption patterns. This makes it even more important that established economic leaders assume their historical responsibility and reduce their environmental footprints to give emerging economies equal opportunities to develop. However, under the concept of ecological debt also some BRIC and MINT countries, especially Russia and China, must increase their efforts towards environmental sustainability.

Acknowledgements

This research was partially funded by a grant from the Institute of Global Environmental Studies (IGES), Japan.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2019.02.103.

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